ANNALS of Faculty Engineering Hunedoara
– International Journal of Engineering
Tome XV [2017] – Fascicule 3 [August]

ISSN: 1584-2665 [print; online]
ISSN: 1584-2673 [CD-Rom; online]
a free-access multidisciplinary publication
of the Faculty of Engineering Hunedoara

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DIAGNOSING RISING DAMP IN RESIDENTIAL BUILDINGS: LESSONS FROM THREE CASES

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Abstract: Dampness is a subject area plagued with misunderstandings over terminology and thinking. Rising damp, a type of dampness, is one of the most severe phenomena that leads to decay and deterioration of both old and modern types of buildings. This study sought to diagnose the problem of rising damp in the walls of three residential buildings using a four-stage approach to damp investigation (i.e. visual inspection, non-destructive testing, destructive testing and laboratory assessment study). The stage 1 approach (visual inspection) showed that blistering of paints, flaking of mortar, surface efflorescence, among others were the key symptoms of rising dampness identified with the three buildings. The stage 2 approach (non-destructive testing) showed that the walls of all the buildings were affected by dampness. The stages 3 and 4 approaches (destructive testing and laboratory assessment studies) revealed that the mortar samples obtained from the three buildings were affected by different salt groups. The study concludes by revealing that although all the salts identified in the current study can be damaging, sodium sulphate (Na_2SO_4), magnesium sulphate ($MgSO_4$) and magnesium chloride ($MgCl_2$) are more damaging and can result in more extensive decay in the walls of the three buildings than all the othersalt types identified. An understanding of these results is very important because knowing the types of salts present in an affected building will lead to the adoption of appropriate treatment methods to control the problem.

Keywords: Dampness, rising damp, salt attack, residential buildings

1.INTRODUCTION

Dampness is one of the subject areas plagued with misunderstandings over terminology and thinking [1]. It is a major problem associated with many buildings and contributes more than 50% of all known building defects worldwide [2]. It is a very common problem among residential buildings in most tropical countries.

Ghana, a country with hotter and drier climate has experienced dampness for several years [3]. In a study to identify the most dominant type of dampness in 5,800 residential buildings in Ghana, all the surveyed buildings were identified with symptoms related to either rising dampness, condensation or water penetration (including leakages) [3]. However, the most dominant type of dampness was found to be rising damp, as it was identified with 5,037 of the surveyed buildings [3]. Hygroscopic salts that led to surface efflorescence, decayed skirting, dampness below 1.5m and mould growth on walls up to 1m high were among the symptoms identified with rising damp in the surveyed buildings.

This paper presents the findings from a laboratory study that diagnosis the problem of rising damp in the walls of three residential buildings using a four-stage approach to damp investigation. The paper is divided into three main sections. The first section reviews literature on rising damp and salt attack and describes the four-stage approach used to diagnose buildings suffering from dampness. The second section describes the methodology used to carry out the investigation, andthe third and final section presents the results obtained from the laboratory analysis.

2.LITERATURE REVIEW

This section reviews literature on rising damp and the principles of damp investigations.

≡ Rising damp

Rising damp, a world known phenomenon occurs when ground water flows into the base of a building and is allowed to rise through the pore spaces of the materials used in the construction of the building[4]. It is described as the movement of moisture upwards through permeable building materials by capillary action [5]. Rising damp is one of the most severe phenomena that leads to decay and deterioration of both old and modern types of buildings [6]. For several years, researchers across the world have identified the deterioration at the base of walls as a problem related only to the phenomenon of rising damp and the focus of remedial treatments have been on the installation of damp-proof courses (DPCs) [7,8].

A number of published articles have been dedicated to defining the phenomenon of rising damp. In addition to these definitions, the provision of an in depth understanding of the mechanisms involved in rising damp has also been critically presented in literature. According to [9], rising damp results from the capillary flow of ground water into the walls of buildings. Burkinshaw and Parrett [1] defined rising damp as moisture that travels upwards through the pore structure or through small fissures or cracks, or as water vapor against the forces of gravity, typically up a wall or through a floor from a source below the ground. Alfano*et al.*[10]also defined rising damp as the vertical flow of groundwater through a permeable wall structure by capillary action. According to [11], wall base damp must involve a significant amount of moisture sourced from the ground to be ‘rising damp’. Rising damp from the ground is sometimes referred to as ‘true rising damp’. Rising damp usually presents itself by salty browny yellowish patches of plaster/decor just above skirting board height [12].

The absorption and transport of moisture in porous building materials is a complex phenomenon and combines the effects of various driving forces [13, 14]. The capillary rise of water is a phenomenon that occurs through the prevalence of the adhesion forces between water capillary surfaces compared with the cohesion forces of the water itself [13]. The height to which the water rises depends on the interaction among the rate of water ingress in the wall [13], the rate of evaporation [15] and the microstructural characteristics of materials [13]. According to the Jurin’s law, the maximum height of rise for water is inversely proportional to the capillary radius [10].

Rising damp has several impacts on masonry materials. It causes a characteristic distribution of water content inside the affected wall. Normally, excessive dampness occurs at the base of the wall, sometimes up to 20-30% in mass [10], but slowly declines as the height increases [13, 10].The groundwater may sometimes contain salt which can find its way through the walls of a building by capillary action [16]. These salts which include chlorides, nitrates, sulphates, among others travel with the water from the ground up the wall and are left behind when the water evaporates [17, 10]. After many years of active dampness, the salts accumulate in bands indicating the maximum height of rise [10]. The accumulated salts are hygroscopic and tend to absorb moisture from the surrounding environment. The problems of rising damp and salt attack are closely related because the moisture from rising damp can dissolve existing salts in a building material. The water rises up the wall, about a meter or more high and often deposits a horizontal ‘tide mark’. Below this mark there is discoloration of the wall with general darkening and patchiness, and there may be mould growth and loose wallpaper.

≡ Principles of dampness investigation

The most important objective of any dampness study is to identify the lead source of moisture in order to recommend actions to remedy the problem [2]. During the course of an investigation, the sense of sight, touch, taste, smell and hearing as well as communication and analytical skills need to be utilized [1]. The investigator needs to be proficient with a range of specialist equipment, like those for conducting tests, or taking samples for testing at a laboratory [1].

There are four major stages to any dampness investigation (Figure 1). These are visual inspection, non-destructive testing, destructive testing and laboratory assessment study[2, 18, 1].

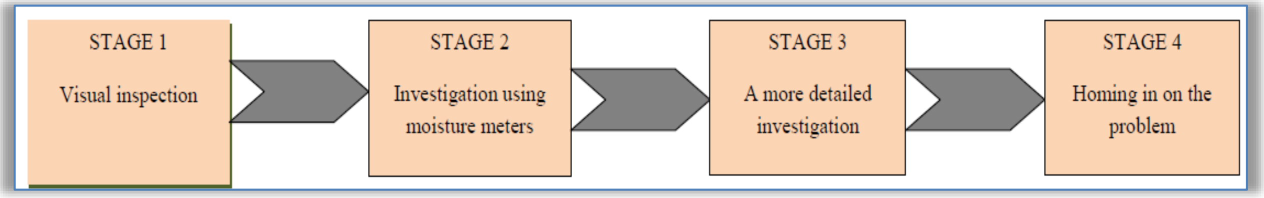

Figure 1. The four-stage approach to damp investigation. (Sources: [2, 18, 1, 19])

The visual investigation stage requires the surveyor to inspect the defect closely and act as a preliminary assessment for further investigation and confirmation of the defect assessed [2, 1]. At this stage the identification of a dampness problem is dependent on symptoms such as staining of water, cracking, rotten timber, decay, blisters, etc. and the diagnosis requires knowledge of the behavior of relevant building materials, construction knowledge and knowledge of the use (past, present and future) of the building.

At stage 2, the most widely used instrument for the diagnosis of dampness is the moisture meter [2, 16, 18, 1]. The two types of moisture meters in use are resistance meters and capacitance meters. Multi-functional instruments that feature a resistance function, capacitance function, a humidity sensor, an air thermometer, a surface thermometer and deep probe facility are now available on the market. This technique may be used to inspect or observe materials or elements of construction in place without causing alteration, damage or destruction to the fabric of the building [2, 18, 1].

The stage 3 investigation requires a collection of techniques that may be used to inspect or observe materials or elements of construction in place, and it involves causing alteration, damage or destruction to the fabric of the building. Tools or techniques that are used involve cutting pieces of materials, drilling, salt test, carbide meter, electronic-thermo hygrometer and mechanical hygrometer [2,18,1]. Oven drying method which is the most accurate method of determining the moisture content of materials involves taking samples, weighing and drying the samples to constant weight in an oven at a suitable temperature (100°C) and then re-weighing. The dampness is expressed by the weight loss achieved through drying as a percentage of the oven dry weight of material being examined [2,18,1].

In stage 4, destructive tests and examinations that require opening up are conducted. More emphasis is placed on the sampling which aims at confirming moisture conditions within structural elements (primarily walls and floors) by drilling out masonry samples [1]. The decision on where samples are drilled depends on the kind of investigation undertaken and prevailing site conditions [1]. A typical investigation could first involve sampling at various positions laterally to confirm a damp zone, followed sometimes by vertical sampling where damp patches extend upwards. A typical stage 4 investigation of an average-sized house with very average moisture conditions could involve drilling 10-12 holes [1].

3. MATERIALS AND METHODS

This study sought to diagnose the problem of rising damp in the walls of three residential buildings using a four-stage approach to damp investigation. A multiple case study approach, which involves three buildings, was adopted for the study. These buildings were selected because they had been severely affected by dampness, and therefore offered suitable cases for the study. The first case of this study was a three-bedroom semi-detached residential bungalow situated at Danyame and belonging to the Department of Urban Roads in Kumasi, Ghana (Figure 2). The second case was a three-bedroom residential building located at Deduako, a suburb of the Oforikrom sub-metro which also falls under the Kumasi Metropolitan Assembly (Figure 2). The building in Case 3 was situated at Kwamo, a suburb of the Ejisu-Juaben Municipal Assembly, one of the 27 administrative and political districts in the Ashanti Region of Ghana (Figure 2).

Figure 2. The three buildings adopted for the study

The methodology used to carry out the study is further elaborated under the four-stage approach to damp investigation as follows:

≡ **Stage 1-Visual inspection**

The visual inspections (Stage 1) were conducted through the observation of the surrounding areas, checking of the damp zones and visually predicting the causes of the dampness based on the symptoms identified. Furthermore, examinations of the exteriors of the buildings from street level and from higher access (roofing, rain water gutters, etc.) were carried out for any obvious defects. Also, the interior parts of the buildings were examined to determine areas affected by dampness.

≡ **Stage 2- Non-destructive testing**

The non-destructive testing (Stage 2) was carried out using the PCE -MMK1 universal moisture meter to identify the problematic areas where samples were collected for further analysis. The moisture content measurements were taken on walls which showed symptoms such as blistering of paints, peeling of paints, staining, mold growth, etc. Grids of 300 mm× 300 mm were drawn on the surfaces of affected walls and moisture meter readings were recorded. Maximum moisture content and relative humidity for masonry materials like cement mortar are recorded at 3.0% and 100% respectively. The wall is considered a very wet zone where the moisture content recorded is greater than 2.8% and the relative humidity ranges between 22% rH-100% rH; a moist condition is recorded where the moisture content ranges between 1.5%-2.8% and the relative humidity lies between 18% rH-21% rH; and a dry condition or level of dampness is recorded where the moisture content is less than 1.5% with relative humidity ranging between 6% rH and 20% rH.

≡ Stages 3 and 4- Destructive testing and Laboratory assessment studies

The stages 3 and 4 approaches employed in this study involved sampling of mortar by adopting approaches used in previous studies [12, 16, 18, 1, 20]. The walls of the buildings were constructed using sandcrete blocks and mortar joints of 150 mm thick. Mortar samples were selected because studies have confirmed that mortar is the dominant path through which water rises in walls of buildings [21, 4].

The equipment and materials used to obtain the mortar samples from the three cases included cordless drills, sharp tungsten carbide drill bits, 35 mm camera film cases for holding samples, plastic resalable sample bags, sharp 65 mm bolster, small piece of card for collecting dust, PCE MMK1 universal moisture meter with deep probes, rule, note pad and labels.

≡ Analyzing the mortar samples from the three cases

Mortar samples were sent to the Chemical Laboratory of the Department of Chemistry at the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana, for ion chromatography tests. Equipment used in the analysis included Ion Chromatography (Metrohm 861 Advanced Compact IC), mechanical shaker, 100 ml measuring cylinder, satorious extend analytical balance, centrifuge tubes (15 ml and 50 ml), wash bottles and volumetric flasks (2000 ml, 1000 ml, 100 ml). For all the ions measured in the mortar samples, where the percentage exceeds the acceptable safe limit of 0.02%, they were considered unsafe and vice versa [16, 18, 20].

4. RESULTS AND DISCUSSIONS

The results from the study are presented and discussed under the four main approaches adopted.

≡ Stages 1 and 2 investigations – Visual inspection and non-destructive testing

In Case Study 1 the visual inspection carried out on the building led to the identification of damp patches all around the bases of the external walls. Apparently, the internal walls were quite healthy and showed no symptoms or signs of dampness. Moisture contents recorded from the internal wall finishes and skirting were less than 1.0% indicating that they were dry. No stains or signs of deterioration were found on the internal wall faces. However, on the external faces of the walls, high readings, some up to about 2.4% were recorded from the moisture meter. Symptoms such as blistering of paints, flaking of mortar, surface efflorescence, and damp patches in horizontal bands were identified on all the external walls in Case 1 (Figure 3a).

The moisture meter was used to measure moisture contents in the walls of all the four orientations (eastern, western, northern and southern) of the building in Case 1. The moisture measurement showed that all the walls were affected by dampness. However, the walls in the western orientation recorded the highest moisture contents as leakages from defective plumbing works combined with other sources of moisture. The moisture contents recorded on the walls of the two bathrooms within Case 1 were very high and reached heights of 1.2 m (Figure 3b). This is very unusual as dampness on the walls of the other rooms reached maximum heights of 600 mm.

Figure 3a. Some symptoms of dampness identified from the building in Case 1 (Source: [22])

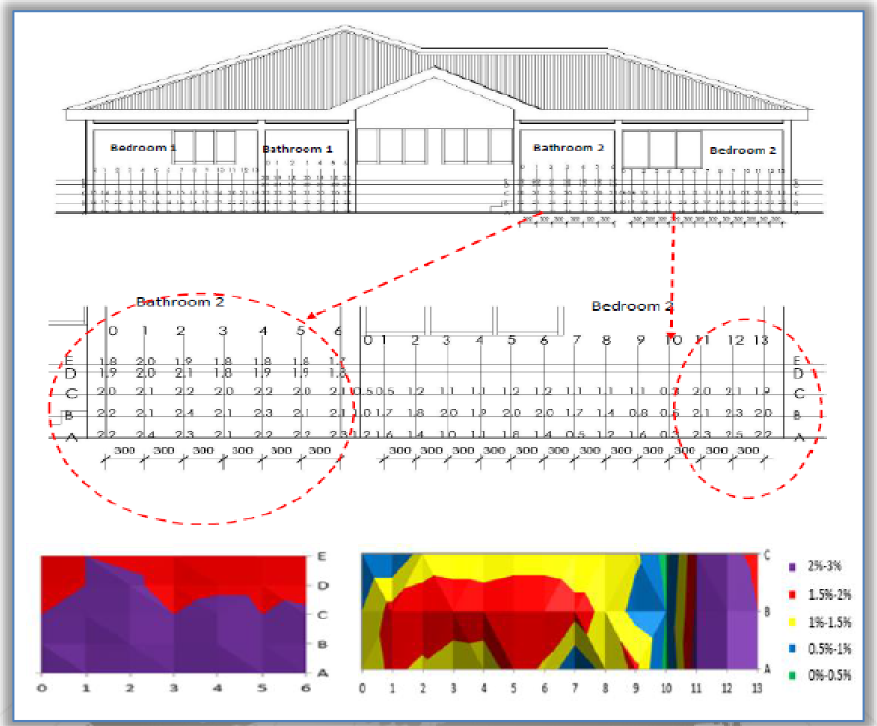

Figure 3b. Measured moisture contents on the walls shown in contour maps (Source: [22])

Figure 4a. Some symptoms of dampness identified from the building in Case 2 (Source: [23])

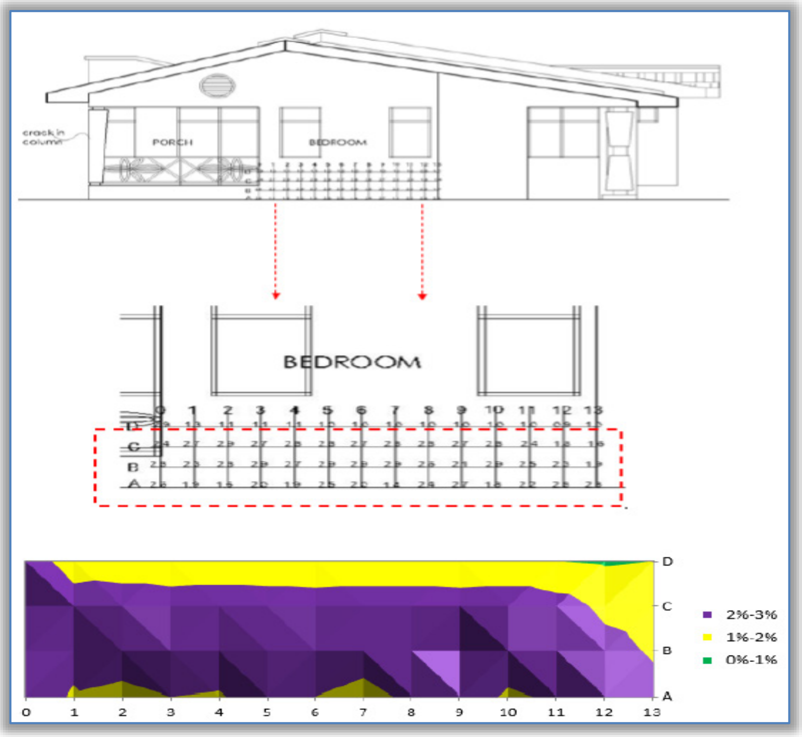

Figure 4b. Measured moisture contents on the walls shown in contour maps (Source: [23])

In Case 2 the site inspection carried out on the building also led to the identification of several symptoms. These symptoms included cracks in columns probably due to salt attacks, greenish stains on walls, blistering of paint, brownish yellow stains on walls, flaking of mortar, etc. (Figure 4a).

Results from the moisture content measurements on the external walls of the building in Case 2 further showed that the walls in the eastern orientation were severely affected by dampness. These damp zones are indicated in purple color in the contour map shown in Figure 4b. Though there existed low level of dampness on some of the grids (for instance A8), dampness recorded in majority of the zones were between 1.5% and 2%, an indication of the severity of the problem. This orientation of the wall was very close to a river which served as a source of water ingress into the walls of the building.

For the building in Case 3, the site inspection revealed symptoms similar to those in Cases 1 and 2. Symptoms of dampness were identified on the external walls of all the four orientations and were very severe in the walls of the washrooms and the adjoining bedrooms. Blistering of paint, flaking of plaster and surface efflorescence were evident on most of the external and internal wall surfaces (Figure 5a). Dampness was evident in all the walls but was very pronounced in the walls located in the western orientation, rising to a maximum height of 1200 mm.

Figure 5a. Some symptoms of dampness identified from the building in Case 3 (Source: [24])

The distribution of moisture contents along and across the faces of the severely affected walls of the building in Case 3 showed that the internal walls of the bedroom oriented in the western direction were severely affected by dampness. The severity of the problem was due to combinations of moisture from sources such as the ground and defective plumbing works in the bathrooms.

The severely affected zones in Figure 5b is shaded in the purple color. In these zones, all the moisture contents recorded on the walls ranged from 1.5% and above. This indicates that dampness was very severe and further studies should be conducted in these areas.

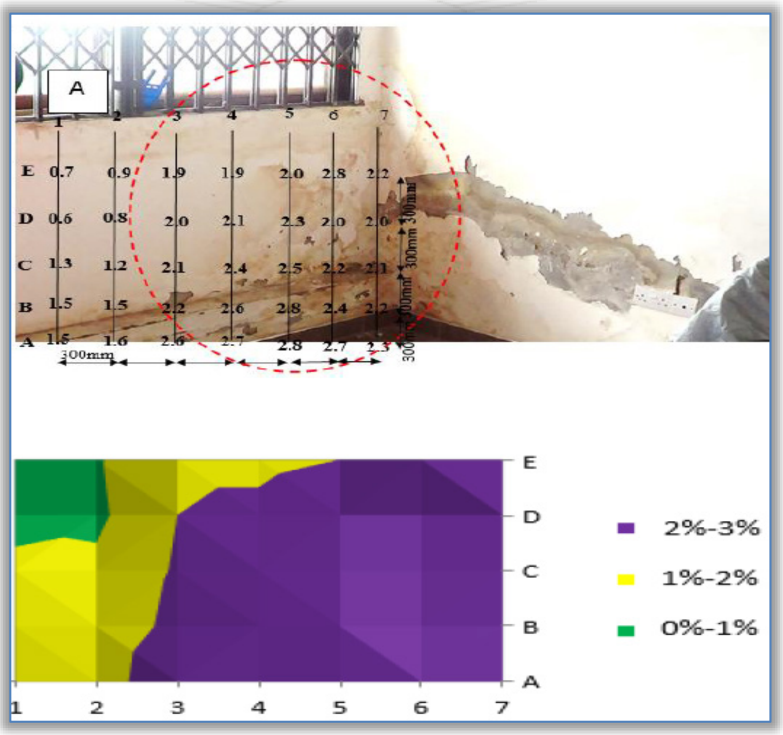

Figure 5b. Measured moisture contents on the internal walls shown in a contour map (Source: [24])

≡ Stages 3 and 4 investigations - Destructive tests and laboratory assessment study

In the Stage 3, mortar samples were drilled from the severely affected zones (damp zones) shaded in the red and purple colors on the contour maps. The samples were taken through the Stage 4 investigation where the presence of salts was determined by ion chromatography. Results obtained for ionic contents of the mortar samples collected from the three cases are presented in Figures6a, 6b, 7a and 7b for samples taken from depths 0-25, 25-50 and 50-75 mm respectively.

The findings from this study only present the most predominant cations and anions identified in the mortar samples collected from the walls of the buildings in the three Cases. The results are presented in Figures 6and7. For the buildings in Cases 1 and 2, the maximum height of rise of the dampness was at depths of 900 mm, whereas for that in Case 3, the maximum height of rise was 1,200 mm. Only the results obtained for the ionic concentrations at the maximum heights of visible dampness for the three buildings were considered in this study. This is because at these heights, most of the water had evaporated and the actual concentrations of the ions could be determined.

The results showed that at the maximum height of visible dampness (i.e. 900 mm), magnesium (Mg^{2+}) is the most predominant cation in the mortar samples collected from Cases 1 and 2 followed by sodium (Na^{+}) and potassium (K^{+}) in that order. Percentage concentrations of these ions exceed the acceptable safe limit of 0.020% [16, 18, 20] and the concentrations decreased with increasing depth.

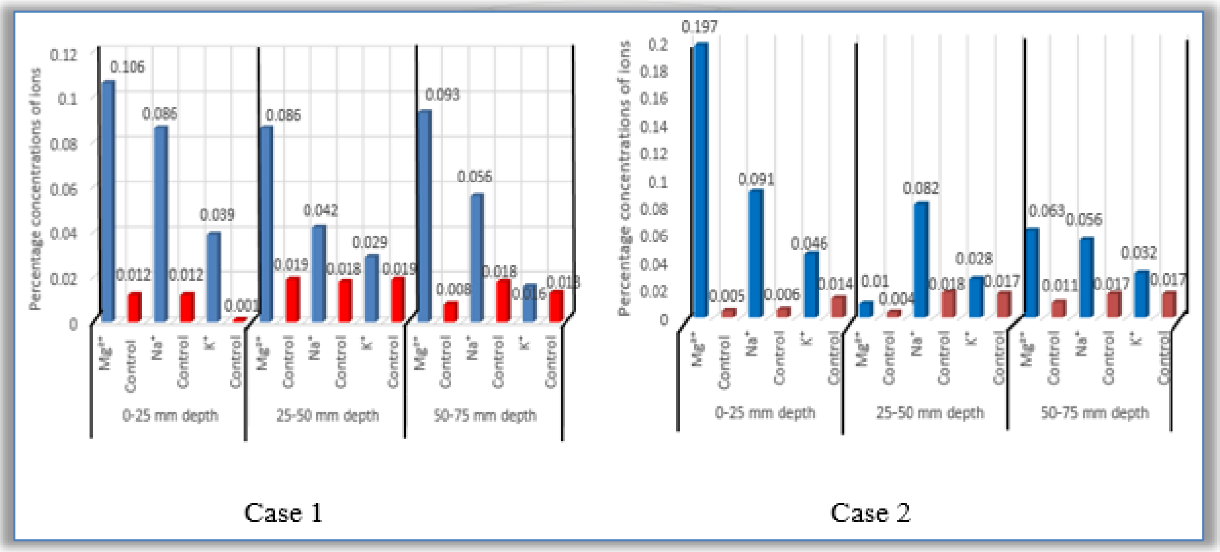

Figure 6a. Comparison of ionic concentrations of most predominant cations from Case 1and Case 2 at heights of 900 mm for different depths.

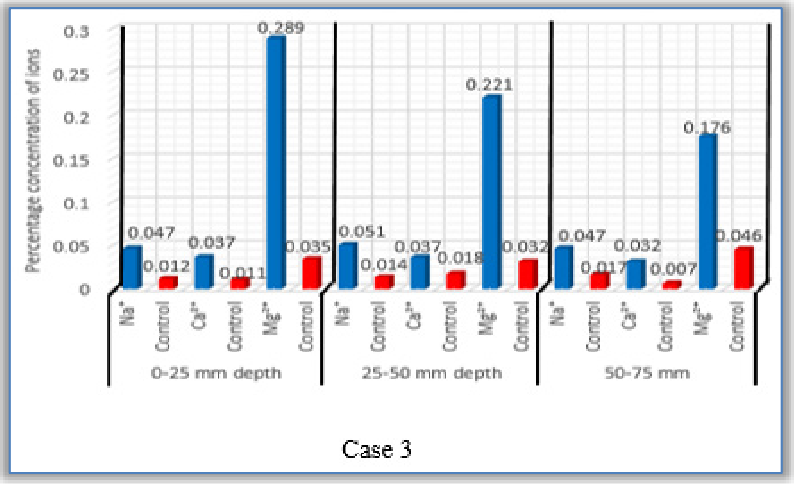

Figure 6b. Comparison of ionic concentrations of most predominant cations from Case 3 at heights of 1.2m for different depths

For the samples collected from Case 3, the results (Figure 7b) show that at the maximum height of visible dampness (1200 mm), Mg^{2+} is the most predominant in the mortar samples collected, followed by Na^{+} and Ca^{2+} in that order. Percentage concentrations of these ions exceed the acceptable safe limit of 0.020% [16, 18, 20].

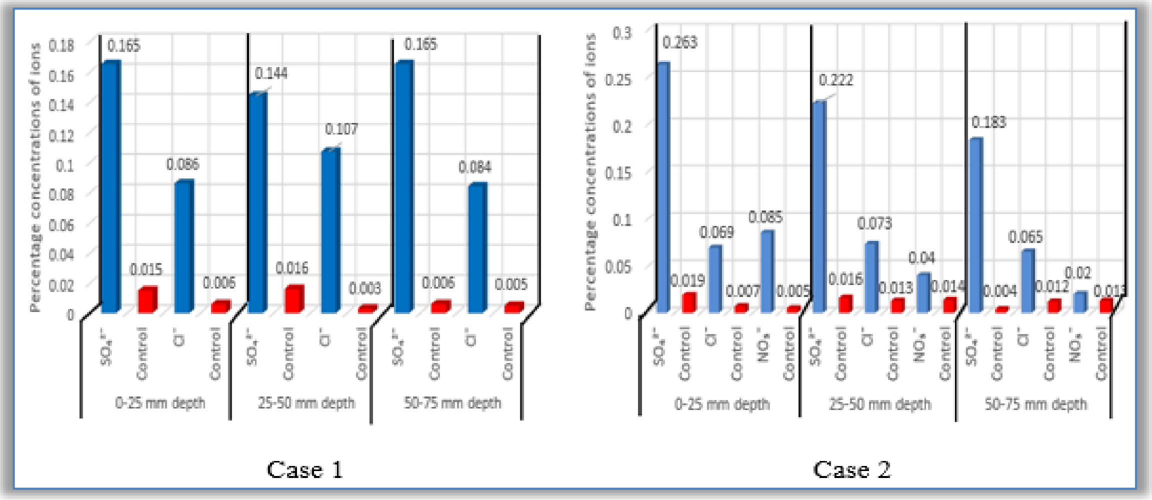

Figure 7a. Comparison of ionic concentrations of most predominant anions from Case 1 and Case 2 at heights of 900 mm for different depths.

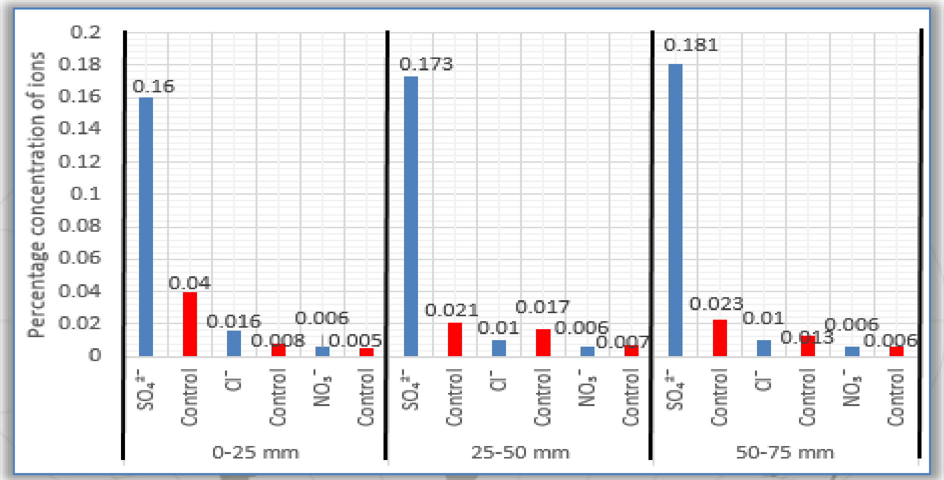

Figure 7b. Comparison of ionic concentrations of most predominant anions from Case 3 at heights of 1.2 m for different depths.

The results further show that the anions, sulphate (SO_4^{2-}) and chlorides (Cl^-) were also predominant at the maximum heights of 900 mm for the buildings in Cases 1 and 2. Similarly in Case 3, the most predominant anions identified at the maximum height of visible dampness were SO_4^{2-} and Cl^-, with nitrates (NO_3^-) in smaller quantities.

For better clarification of the findings, mortar samples were obtained from the unaffected parts of the building (1.5 m above the damp areas) in the three cases, and ionic tests were further performed on them. The results obtained for the control samples from the buildings in the three cases collected at 1.5 m above the height of visible dampness show that the salt contamination was low on the most predominant anions (SO_4^{2-} and Cl^-) and cations (Mg^{2+}, Na^+ and K^+). These predominant ions identified had total concentrations below the acceptable safe limit of 0.020% [16, 18, 20], indicating no significant dampness and damage to the walls. No significant dampness was found in these areas because the mortar samples were original samples taken from the walls above the regions of visible dampness.

5. LESSONS FROM THE FINDINGS

From the results obtained from this study, it can be seen that at the maximum height of visible dampness, the percentage concentrations of the most abundant cations and anions appear to decrease with increasing depth of samples. Also, most of the salts from the mortar samples are highly concentrated on the wall surfaces at depths 0-25 mm than at depths 25-50 mm and 50-75 mm. This trend means that crystallisation occurred near the surfaces of affected walls. Bucea *et al.*[25] found that deterioration of walls of buildings were due to salt crystallization on both concrete exposed to sulphate solution and mortar exposed to either sulphate or chloride solutions.

At the various depths (0-25 mm, 25-50 mm and 50-75 mm) for the maximum height of 900 mm and 1200 mm respectively, Mg^{2+}, Na^+ and K^+ were identified as the most predominant cations and SO_4^{2-} and

Cl^- as the most predominant anions. The ions identified had total concentrations above the acceptable safe limit of 0.020% [16, 18, 20]. Thus, magnesium sulphates ($MgSO_4^{2-}$), magnesium chlorides ($MgCl_2$), sodium sulphate (Na_2SO_4), sodium chloride (NaCl), potassium sulphate (K_2SO_4) and potassium chloride (KCl) appear to be the most abundant salts present at the maximum height of visible dampness in the buildings within the three cases. These salts are in concentrations likely to cause damage to the walls of the buildings internally [16, 18, 20].

Although all the salts identified in the current study can be damaging, Na_2SO_4, $MgSO_4$ and $MgCl_2$ are more damaging and can result in more extensive decay in the walls of the three buildings than all the othersalt types present [26, 8, 27]. Normally, the magnesium sulphate salt shows a slower rate of decay compared with the other damaging salts, but it is still dangerous [28]. The mixtures of sodium, chlorides, nitrates, sulphates and the likes in masonry walls suggest clear scenarios of rising dampness [25].

6. CONCLUSION

Rising damp is common in buildings around the world and it plays a major role in the decay of masonry buildings. This study sought to diagnose the problem of rising damp in the walls of three residential buildings using a four-stage approach to damp investigation. The stages included the visual inspection, non-destructive testing, destructive testing and laboratory assessment study. The conclusion from the study is presented to include the following:

– Results from the visual inspection showed that all the three buildings were associated with symptoms such as blistering of paints, flaking of mortar, surface efflorescence, and damp patches in horizontal bands;

– Also, the results from the non-destructive testing showed that each of the four orientations in each of the buildings was affected by dampness. However, the walls located in the western orientations of the buildings in Cases 1 and 3 were severely affected by dampness. For the building in Case 2, the results showed that the walls located in the eastern orientation were severely affected by dampness; and

– Different salt groups were identified in the mortar samples collected from the severely affected parts of the walls and tested in the laboratory. Magnesium sulphates ($MgSO_4^{2-}$), magnesium chlorides ($MgCl_2$), sodium sulphate (Na_2SO_4), sodium chloride (NaCl), potassium sulphate (K_2SO_4) and potassium chloride (KCl) salts were abundant salts in the mortar samples. These salts were in quantities capable of causing severe damages to the buildings.

The results from this study have been well discussed and interpreted to confirm the existence of rising dampness in the buildings surveyed. An understanding of these results is very important because knowing the types of salts present in an affected building will lead to the adoption of appropriate treatment mechanisms to control the problem.

Acknowledgement

The authors would like to express utmost gratitude to the staff of the Geotechnical Division of Building and Road Research Institute (BRRI) of the Council for Scientific and Industrial Research (CSIR) in Kumasi for their assistance. The authors also wish to express their sincere gratitude to Mr. Stephen Boandoh, a Postgraduate laboratory assistant at the Department of Chemistry of the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana for his great assistance in the chemical salt analysis.

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